High Confidence Active Safety Control in Automotive Cyber Physical Systems

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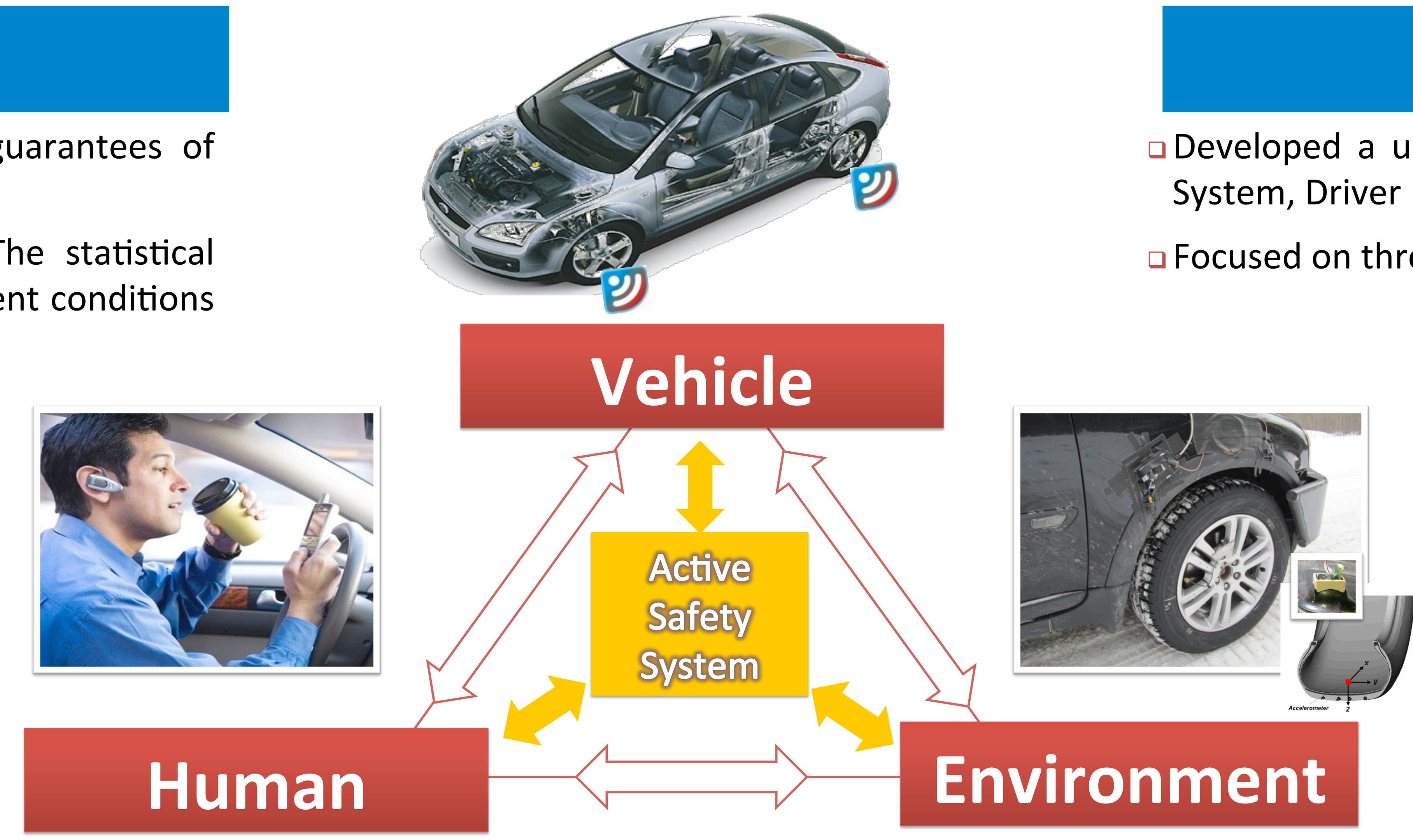
Industrial Partners: Ford Motor Company, Pirelli SpA, Volvo

Background and Objectives

- Today no design methodology provides performance and robustness guarantees of autonomous or semiautonomous systems.
- Current industry standard is to use extensive on-road vehicle tests. The statistical relevance of such tests is questionable given the wide variety of environment conditions and drivers behavior.
- Our objectives:
  - ✓ Develop a vehicle CPS where the degree of autonomy is continuously changed in real-time. A continuum of options between "driver in total control of the vehicle" and "autonomous drive".
  - ✓ Robustly guarantee passenger safety, *during design,* with respect to uncertainty in driver behavior and road friction coefficient.
  - ✓ Quantify uncertainty in driver behavior and road friction coefficient in order to provide guarantees for statistically dangerous scenarios.
  - ✓ Achieve high confidence safety through sensing and control for the quantified uncertainty.



Current Results

- Developed a unified framework for the collaboration of three teams (Vehicle Control System, Driver Behavior and Tire Dynamics).
- Focused on three areas:
  - (A) **Tire-Road uncertainty quantification by using Cyber Tires**
    Development and experiments of friction coefficient estimation algorithm using lateral acceleration only inside contact patch and modified lateral deflection model.
  - (B) **Modeling and real-time identification of driver behavior**
    Constructed a method to use in-vehicle camera and wireless body sensor networks to track driver. Developed an algorithm for online clustering in non-Euclidean space to generate distracted drivers prediction models. Preliminary validation with human studies.
  - (C) **Design of provably safe active stability controllers**
    Development of hierarchical predictive control system with adjustable degree of autonomy. Experimental/simulation tests of different scenarios.

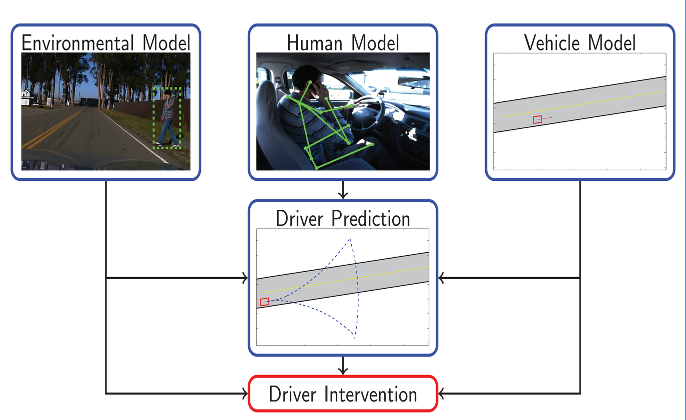
Distracted Driver Model

Background

- Nearly 25% of traffic accidents are caused by inattention of drivers and this number is growing.
- Internal sensors are more reliable and have been proven useful in modeling human movement.

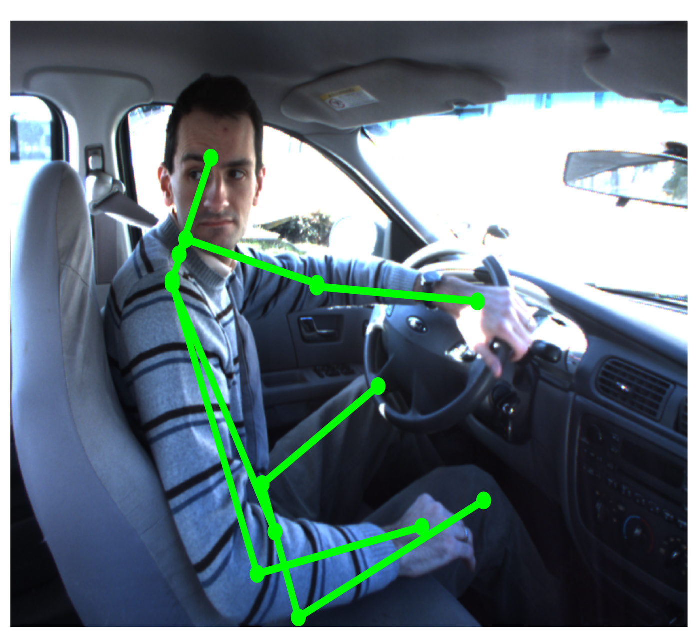
Objective

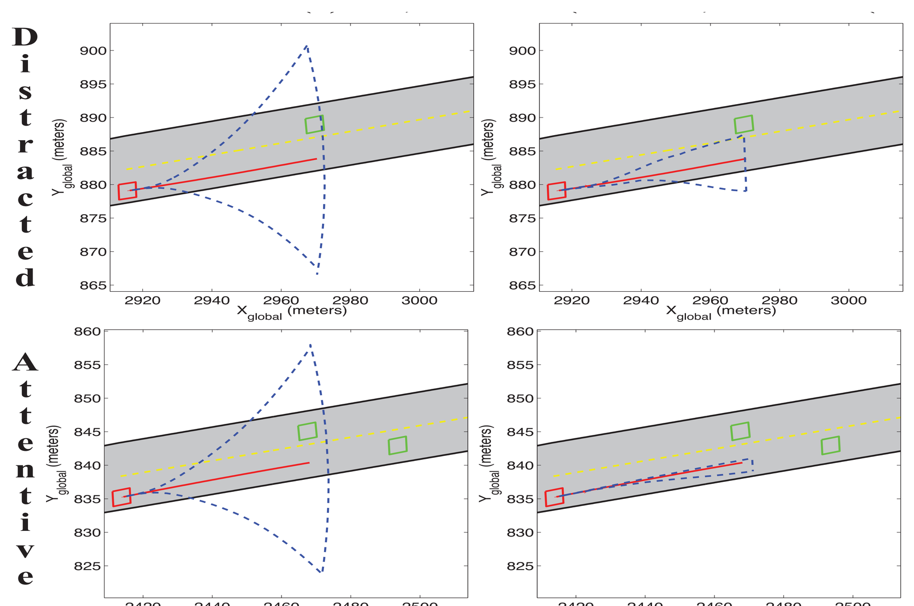
- Leverage internal sensors to model driver movement.
- Construct a real-time prediction scheme given this model.
- Aid the driver with the verifiably safe controller when he/she requires help according to the prediction scheme.



Current Results

- Track the driver in real-time using 3D data.
- Developed an online clustering technique in non-Euclidean space to generate a prediction.
- Assess the utility of the driver model by considering a 4-scenario CarSim generated experiment.
- Empirically proved the utility of incorporating the human model while generating prediction.





	Accuracy of Prediction	Precision of Prediction	Recall of Intervention	Precision of Intervention
Existing System	100%	0%	100%	0.31%
Our System	78%	82%	100%	68%

Next Steps

- Transform prediction into determination of when autonomous controller should take over.
- Incorporate the real-time tracking scheme and prediction scheme into a car for real-life testing.

Provably Safe Control Design

Background

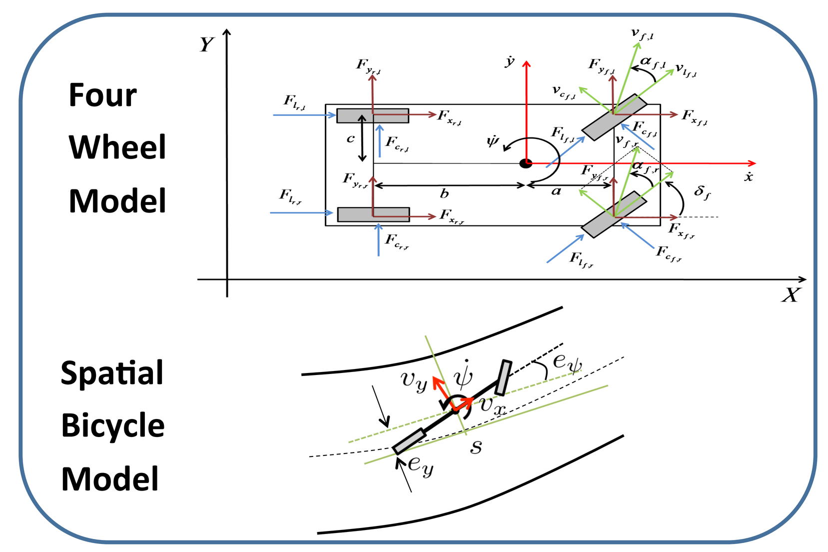
- High-fidelity model is required for extreme conditions, i.e. high speed on ice.
- Computational complexity prevents real-time implementations (~20ms) with long prediction horizons on standard computing platforms.
- Existing active systems lacks safety guarantees.

Objective

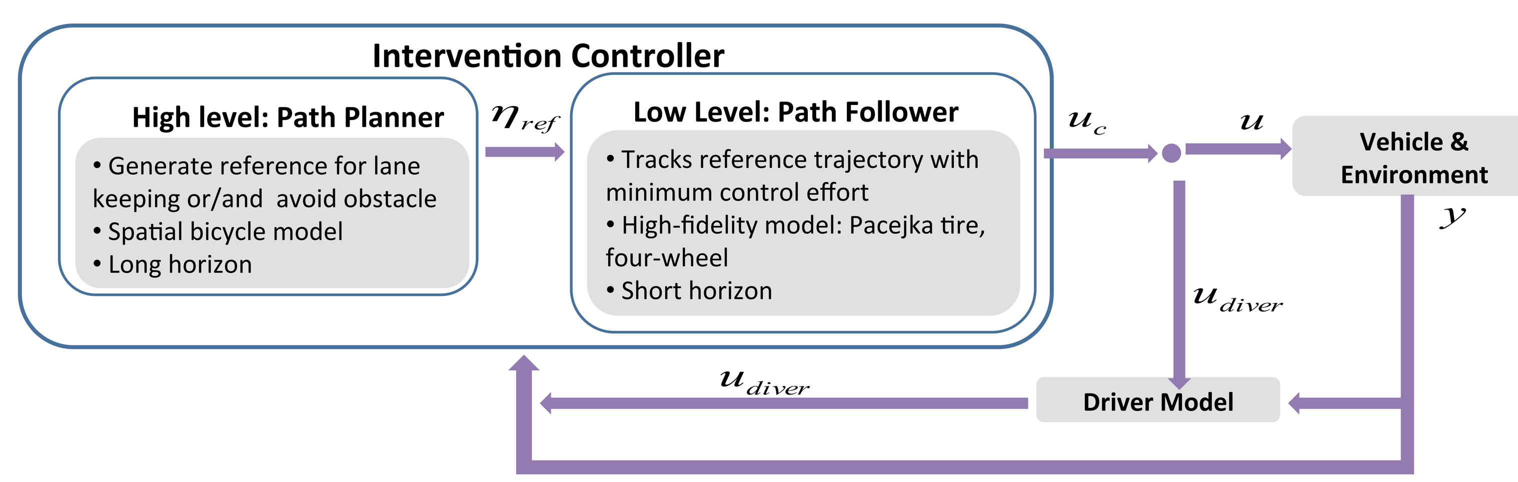
- Design a safe system which provides guarantees w.r.t. uncertainties in driver, friction and vehicle modeling.
- Real-time implementable.

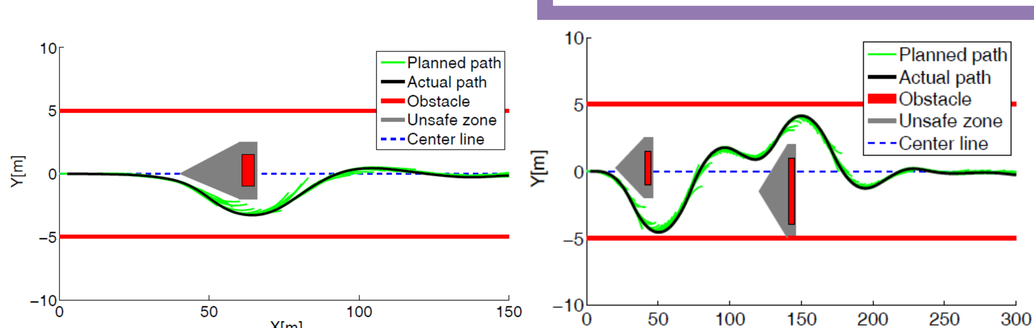
Current Results

- Development of hierarchical control system with adjustable degree of autonomy.
- Development of simplified spatial bicycle model

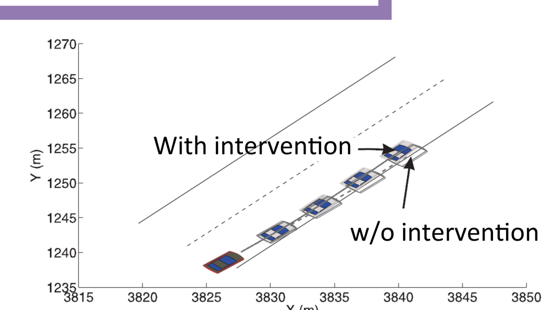


- Experimental tests of multiple obstacle avoidance with high speed on ice, real-time and distracted driver.
- Simulation of intervention controller with an existing "simple" driver model, in a road departure scenario.





Experimental results of obstacle avoiding with distracted driver



Simulation results of driver intervention with "simple" driver model

Next Steps

- Integrate controller with advanced driver model been developed
- Robust design of hierarchical scheme with guarantees.

Cyber Tires - Friction Estimation

Background

Estimation of tire forces and tire road friction coefficient can lead to significant improvements in vehicle control systems.

- Vertical forces are directly related to rollover.
- Friction coefficient provides a good measure of the available tire forces.

Objectives

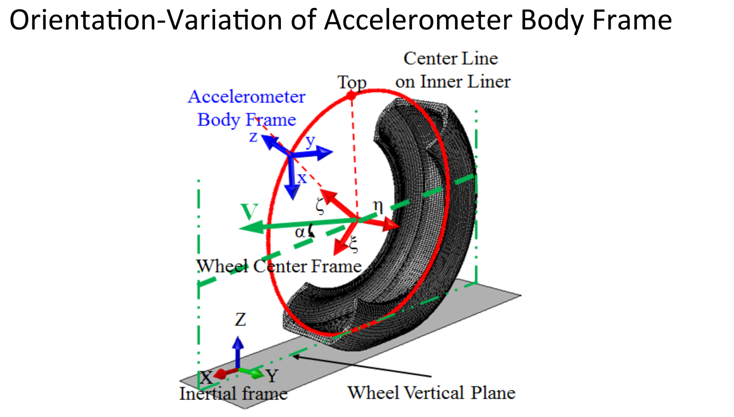
Use tire based sensors and modify tire lateral deflection model for:

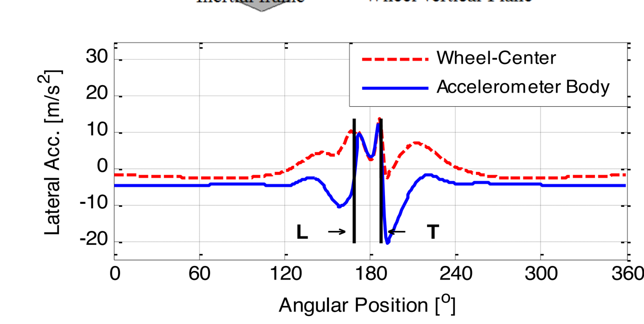
- Understanding Tire Deformations
  - Acceleration and Deflection Profiles
- Developing Estimation Algorithms
  - Friction Coefficient
  - Tire Forces

Current Results

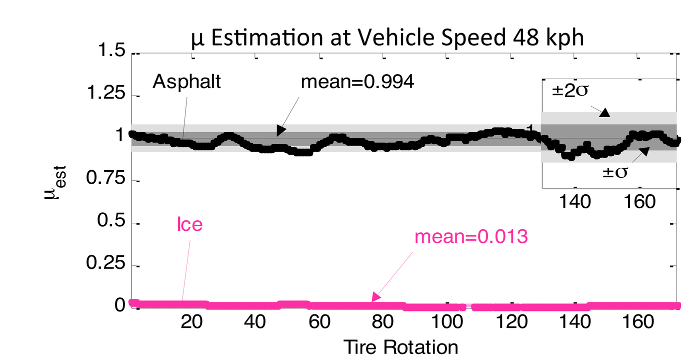
- Tire-Road Friction Coefficient Estimation Algorithm

Orientation-Variation of Accelerometer Body Frame

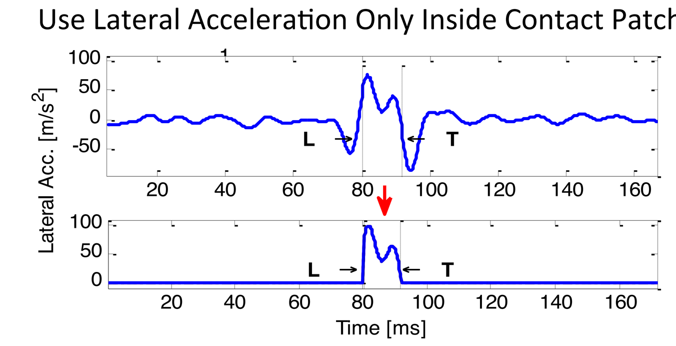


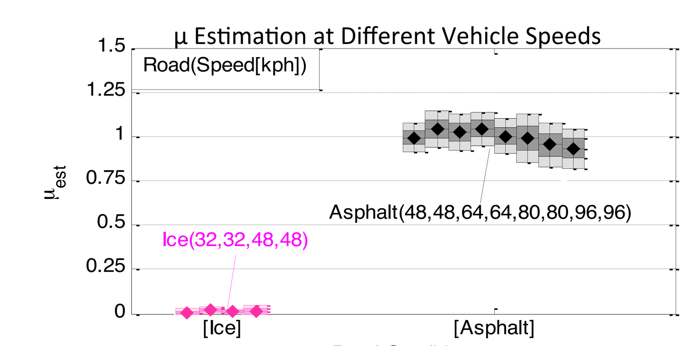


- Experiments (Asphalt & Ice)



Use Lateral Acceleration Only Inside Contact Patch





Next Steps

- Improve the estimation algorithms to compensate for steering.
- Develop methodology for robustness to uncertainties, e.g. much noise on snow and concrete.